along the northern boundary toward the Atlantic, thus inducing on their fronts an unusual frequency of southerly winds; (2) the presence of this oceanic cyclone off the coast of Alaska and the British Northwest operated to maintain relatively high temperatures in those regions, so that when the barometric gradients were favorable to a flow of polar air equatorward the gravitational pull in that direction was less than usual because of the warmth of the polar air. As a result, no pronounced cold waves swept southward.

The object of this and similar studies [5] is to evaluate the influence of the North Pacific pressure distribution upon the weather of the North American Continent as a factor in the daily forecasts, also to discover to what, if any, extent a foreknowledge of that distribution may be helpful in seasonal forecasting, assuming, of course, that it may be possible to forecast the pressure distribution over the Pacific, a possibility not yet demonstrated.

It is highly improbable that useful generalizations as to the sequence of weather in North America can be drawn from the consideration of the pressure distribution over the northeast Pacific for a single winter and none will be attempted.

[5] Henry, A. J., Seasonal forecasting of precipitation, Pacific Coast States, MONTHLY WEATHER REVIEW 49: 213-219. Pressure over northeastern Pacific and weather in United States December, 1924, and January, 1925, 53: 5-10.

The work thus far is not entirely fruitless since it confirms in a general way the conclusions recently set forth by Sir Frederick Stupart.[6]

There is a growing belief on the part of meteorologists that the cause of unusual seasonal variations is in some way related to the conditions that prevail in Arctic and Antarctic regions.

The North American Continent is unfavorably situated with respect to the Arctic as compared with European countries. Instead of a warm oceanic current that makes its way far into polar seas, as in Europe, North America is hedged in by a frigid polar sea and a great interior continental area devoid of meteorological outposts whence useful information as to weather conditions might come. Progress in ameliorating this need is being made, thanks to the Canadian Weather Service. Another hindrance to weather prevision beyond 24–36 hours is a lack of knowledge of free-air conditions along the western coast on the approach of an oceanic cyclone and back of all this lies the most difficult problem of anticipating the pressure distribution over the vast extent of water surface which separates the North American Continent from Asia and the islands of the Far East.

[6] Stupart, F., The variableness of Canadian winters. Presented before the British Association for the Advancement of Science at its Toronto meeting of August, 1924, abstracted in this Rev. 52: 351.

TORNADOES OF THE UNITED STATES, 1916-1923[1]

By HERBERT C. HUNTER

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With the year 1916 the Weather Bureau resumed the systematic collection for the whole country of tornado statistics which had ceased at the end of 1897. The important tornadoes during this 18-year interval had, however, been described, chiefly in the MONTHLY WEATHER REVIEW, likewise some minor ones of special interest; while in a few States there was sustained effort to list every storm of great violence, tornado or not.

The results for eight years, to the end of 1923, have been compiled and are now shown in Table 1. The study covers the distribution by States and the losses of both life and property. The details were printed regularly, year by year, in the Report of the Chief of the Weather Bureau, with a chart for each year to illustrate the occurrence.

The following new items, coming to notice since the respective reports went to press, have been included in the statistics:

Missouri.—One death from the tornado of June 1, 1917, in Jackson County.

New England.—The violent storm in Massachusetts, Norfolk, and Plymouth Counties, about 4 p. m., August 31, 1920, in view of further information, is considered a tornado. There were no fatalities, but the property loss was about $200,000.

North Dakota.—A storm, not known previously, is reported as a tornado, in Traill County, north of Mayville, August, 1919, about the 25th. The damage was unimportant and almost undoubtedly no lives were lost.

In a few instances the total number of deaths or total damage from a number of tornadoes within a single State during a month or other short period of time was printed, but the exact number of those tornadoes that did involve loss of life or property loss to a certain amount was not printed and is not now known. In order to show as well as possible how many tornadoes caused deaths or heavy damage it has been thought best to allot the totals in a somewhat unequal way, about as is most frequently found to happen with similar groups of tornadoes when all the details are still accessible. The cases where such allotment enters, rather than the complete details, are so few that the greatest possible error from this cause in the figures of Table 1 is of little consequence.

Two columns are introduced in Table 1 which relate not to the storms classed as tornadoes, but to severe winds that seem not to have been tornadoes, including hurricanes of tropical origin, thunderstorm squalls, and other violent winds which can cause loss of property or of life. The division in these columns of the deaths and property damage reported from the Maryland-Delaware section and the New England section between the individual States that compose those sections can not now be made exactly (as is entirely possible for the tornadoes), but is given approximately. For several States, as a footnote indicates, the estimates of damage for these miscellaneous winds are known or believed to be decidedly incomplete.

In securing this material and compiling these reports, from 1916 onward, the Climatological Service has been the principal means. This service assigns a certain area, almost always an exact State, to each of 45 section directors. The tornado information, like much other material, is assembled and passed upon first by these directors, then the compiling is finished at Washington. By direction of the Chief of the Weather Bureau the work was started and has always been supervised by P. C. Day, head of the Climatological Division; most of the actual compiling at Washington was handled for 1916 by Joseph B. Kincer, but for the subsequent years by the writer. Much assistance has been found in the preliminary table of severe storms, including several

[1] Presented in part to the American Meteorological Society at Washington, D. C., Jan. 2, 1925.

kinds other than tornadoes, printed in the MONTHLY WEATHER REVIEW since March, 1921; this has usually been prepared by Miss Grace W. Carter.

Newspaper sources available at Washington have been of considerable help, and the Weather Bureau officials at stations other than section centers have furnished much information regarding those tornadoes that came within moderate distances of their own stations.

The greatest credit, however, should be given to the section directors for their zealous, faithful efforts to secure accurate information and advise what the nature of each storm seems to have been. The present canvass has a marked advantage over earlier ones, covering 1897 and certain preceding years; for these directors, well distributed over the country and in touch with numerous sources of news within their sections, are apt to learn of storms in remote districts which would readily escape the notice of a single worker or a group in one city trying to collect items for the whole country.

Recently an attempt was made to test the completeness with which the newspapers of Washington report tornado information for the whole country. For over five months, not consecutive, every issue of two dailies, relying on different press services for their items, was thoroughly examined for news of violent storms, whether termed tornadoes or not. The result indicated that at least one-sixth of the tornadoes now reported by the Climatological Service and other Weather Bureau personnel would remain unknown if the two periodicals in question were used as the only sources of information.

It is a disadvantage, however, to have the final counts for the States rest chiefly upon so many diverse judgments. Naturally some directors are far more conservative than others in deciding whether a puzzling storm is to be classed as a tornado; and the storms that are difficult to classify form a large part of the whole number.

The Weather Bureau defines a tornado in Instructions for Preparing Meteorological Forms, paragraph 138*a*, thus:

> A tornado is a violent local storm, in connection with which is usually noted a well-defined, pendant, funnel-shaped cloud, with attendant rotary winds, often of sufficient violence to prostrate buildings and uproot trees, and leaving unmistakable evidence of rotary winds.

In practice, the information a section director can secure is very often inconclusive. A storm with much likeness to the tornado type may evidence so slight energy that it seems not to deserve the name "tornado"; again, the rotation around a vertical axis may not be established, though a trained observer can usually determine this point months after the occurrence by studying the débris. Furthermore, the total score of a State is much affected, at times, by the surmises as to whether two or three storm-visits a few miles and a few minutes apart, are properly to be considered but one tornado or rather two or three.

In passing upon the material assembled, the Climatological Division has occasionally changed the designation of a particular storm of puzzling character from the section director's decision of "possibly a tornado," which would count as 0 in the tables accompanying this article, to "probably a tornado," which counts as 1. That such transfer from one class to another is occasionally desirable may be judged from the fact that twice, within the 8-year period, a doubtful storm has crossed a State boundary, with the width and general character of its track not notably different in the two States, as far as information was secured; yet one section director had judged the storm "possibly a tornado, but probably not" and the other had reported it "probably a tornado."

The two States which seem to present the greatest contrasts in the matter of classifying difficult storms are Iowa and Georgia. It is thought that the period 1916–1923 was one of rather more than the normal number of violent local storms in Iowa, and of less than the normal number in Georgia; yet a careful contrasting of statistics for these States and those that border on them brings out striking results.

From the beginning of 1916 to the end of 1923 the count of tornadoes in Iowa was 66; the average count per State in the 6 States bordering on Iowa, 27.2; the count in Georgia, 4; the average per State in the 5 States bordering on Georgia, 19.2. The average number of deaths per tornado counted was in Iowa, 0.6; but in States bordering on Iowa, 2.5; in Georgia, 15.8; in States bordering on Georgia, 2.6. The average damage per tornado, as far as reported, was, in Iowa, approximately $67,000; in States bordering on Iowa, $114,000; in Georgia, $375,000; in States bordering on Georgia, $60,000.

It is difficult to avoid the opinion that the plan of assembling and passing upon the material lacks evenness; it seems probable that the methods for securing information and for classifying storms in Iowa, would, if employed in Georgia during the period, have reported more than 4 tornadoes; and, vice versa, that the Georgia methods would in Iowa have reported many less than 66.

There is a greater tendency on the part of most newspapers to brand as a "tornado" a violent storm which results in loss of human life than to apply the term to a similar storm which does not involve loss of life.

In the entire country, from 1916 to 1923, the information secured indicates 754 storms that should be classified as tornadoes, an average of 94 and a fraction per year. Two columns of Table 1 present the numbers by States, the first of them counting only those which originated within the State, but the other all those which affected any portion of the State, whether starting within it or outside it. The count by States of origin gives 753, the other tornado starting in Mexico and crossing the Rio Grande into Texas. No tornado seems to have crossed the Canadian boundary in either direction. The count by States of occurrence gives a total of 810–56 being due to tornadoes crossing State boundaries, a few storms crossing two such lines, but none more than two.

The annual count was greatest in 1917, when there were 121 tornadoes, while 65 was the smallest total for any one year of the eight. This is a smaller range in yearly numbers than would be expected by the chances of occurrence. In Table 2 certain statistics of the tornadoes are assembled by years and are presented with like statistics for the nine years studied by Professor Henry, 1889 to 1897, inclusive.[3]

Among the States for this 8-year period Arkansas leads in number of tornadoes with 76; afterwards come, in order, Kansas, Texas, Iowa, Missouri, and Oklahoma, the last-named reporting just 50. The greatest number for any one State during a single year is found in Arkansas for 1916, 32; while next to it is Missouri, which reported 30 in 1917.

In just eight States there seem to have been no tornadoes during this period. Of the eight, six are in the East, four of the six being of decidedly small area; the other two are in the far West. In the four Territories included in Table 1 there have been no tornadoes reported during the years it covers, nor, so far as known, during any other years.

[3] Reports of the Chief of the Weather Bureau, 1895–1896, 1896–1897, 1897–1898.

TABLE 1.—*Statistics of tornadoes, 1916–1923*

State or Territory	Number of tornadoes, 8 years		Most tornadoes in a year, and the year	Number of years when tornadoes were			Loss of life, 8 years, by—		Most tornado deaths in a year, and the year	Number of tornadoes—			Average loss of life per—		Aggregate reported property losses in thousands, 8 years, from—		Number of tornadoes causing losses of—		Greatest tornado losses in a year, and the year (thousands)
	Originating in—	Occurring in—		Fatal	Not fatal	Absent	Tornadoes	Winds not tornadoes		Fatal to 1 or more	Not fatal	Fatal to 10 or more	Tornado occurring	Fatal tornado	Tornadoes	Winds not tornadoes	$100,000 or more	$1,000,000 or more	
Alabama	30	35	8:1922	8	0	0	180	6	108:1920	[1] 18	[1] 17	[1] 5	5.1	[1] 10.0	$3,797	$4,274	[1] 9	1	$2,155:1920
Alaska	0	0	----------	0	0	8	0	[2] 1	----------	0	0	0	------	------	0	[2] 17	0	0	----------
Arizona	1	1	1:1916	0	1	7	0	2	----------	0	1	0	------	------	(3)	205	0	0	(3) :1916
Arkansas	74	76	32:1916	7	1	0	231	8	91:1916	[1] 32	[1] 44	[1] 6	3.0	[1] 7.2	2,400	266	[1] 3	1	1,502:1921
California	1	1	1:1921	0	1	7	0	15	----------	0	1	0	------	------	17	4,808	0	0	17:1921
Colorado	7	7	2: (4)	1	4	3	5	3	5:1922	2	5	0	0.7	2.5	160	74	1	0	130:1922
Connecticut	0	0	----------	0	0	8	0	[5] 0	----------	0	0	0	------	------	0	(6)	0	0	----------
Delaware	0	0	----------	0	0	8	0	[5] 3	----------	0	0	0	------	------	0	[5] 30	0	0	----------
District of Columbia	1	1	1:1923	0	1	7	0	[5] 1	----------	0	1	0	------	------	(3)	[5] 15	0	0	(3) :1923
Florida	6	6	3:1919	1	2	5	1	37	1:1917	1	5	0	0.2	1.0	53	8,674	0	0	31:1919
Georgia	3	4	3:1921	2	0	6	63	17	33:1920	3	1	2	15.8	21.0	1,500	812	2	1	1,250:1920
Hawaii	0	0	----------	0	0	8	0	[2] 1	----------	0	0	0	------	------	0	(2) (3)	0	0	----------
Idaho	1	1	1:1916	0	1	7	0	0	----------	0	1	0	------	------	(3)	(3)	0	0	(3) :1916
Illinois	23	24	7:1920	5	2	1	149	17	106:1917	12	12	2	6.2	12.4	7,536	706	9	3	3,342:1917
Indiana	15	20	9:1917	3	2	3	131	8	75:1917	11	9	6	6.6	11.9	5,016	1,775	8	2	3,200:1917
Iowa	63	66	13:1919	4	4	0	40	1	29:1918	10	56	1	0.6	4.0	4,446	650	12	0	2,450:1918
Kansas	68	69	18:1923	5	3	0	61	3	42:1917	[1] 12	[1] 57	2	0.9	[1] 5.1	3,622	1,658	11	0	1,870:1917
Kentucky	6	8	4:1917	1	3	4	75	34	75:1917	2	6	1	9.4	37.5	2,080	3,891	1	1	2,000:1917
Louisiana	13	13	5:1923	5	1	2	42	36	25:1923	9	4	1	3.2	4.7	1,260	6,807	2	0	965:1923
Maine	0	0	----------	0	0	8	0	[5] 1	----------	0	0	0	------	------	0	[7] 2	0	0	----------
Maryland	0	1	1:1923	0	1	7	0	[5] 1	----------	0	1	0	------	------	100	[5] 220	1	0	100:1923
Massachusetts	2	2	1: (4)	0	2	6	0	[5] 4	----------	0	2	0	------	------	400	(6)	2	0	200: (4)
Michigan	24	24	6:1920	2	6	0	16	45	12:1920	4	20	0	0.7	4.0	3,082	[7] 182	[1] 5	[1] 2	2,000:1920
Minnesota	9	12	3:1920	4	2	2	99	3	59:1919	4	8	2	8.2	24.8	4,767	[7] 60	3	2	3,500:1919
Mississippi	41	42	11:1921	8	0	0	257	5	135:1920	24	18	8	6.1	10.7	3,698	[7] 196	[1] 9	1	1,500:1920
Missouri	52	57	30:1917	5	3	0	123	9	84:1917	25	32	3	2.2	4.9	3,507	1,216	9	1	1,550:1917
Montana	9	9	7:1923	1	2	5	2	5	2:1923	1	8	0	0.2	2.0	4	45	0	0	4:1923
Nebraska	34	36	6: (4)	3	5	0	7	3	3: (4)	3	33	0	0.2	2.3	902	(6)	3	0	500:1918
Nevada	0	0	----------	0	0	8	0	0	----------	0	0	0	------	------	0	(3)	0	0	----------
New Hampshire	1	1	1:1922	0	1	7	0	[5] 0	----------	0	1	0	------	------	10	(6)	0	0	10:1922
New Jersey	2	2	1: (4)	0	2	6	0	13	----------	0	2	0	------	------	(3)	235	0	0	(3) :(4)
New Mexico	8	8	3:1922	0	5	3	0	0	----------	0	8	0	------	------	19	1	0	0	12:1923
New York	6	6	2: (4)	1	3	4	2	97	2:1920	1	5	0	0.3	2.0	335	4,073	2	0	200:1920
North Carolina	10	11	2: (4)	4	4	0	8	1	3: (4)	4	7	0	0.7	2.0	547	[7] 14	2	0	280:1920
North Dakota	17	19	5: (4)	3	4	1	10	3	8:1923	4	15	0	0.5	2.5	128	1,171	0	0	70:1921
Ohio	18	23	7:1920	4	3	1	40	12	31:1920	8	15	2	1.7	5.0	3,187	[7] 200	10	0	1,512:1920
Oklahoma	46	50	15:1917	7	1	0	144	9	64:1920	[1] 18	[1] 32	4	2.9	[1] 8.0	2,632	2,034	[1] 9	0	1,045:1922
Oregon	0	0	----------	0	0	8	0	9	----------	0	0	0	------	------	0	250	0	0	----------
Pennsylvania	10	11	3: (4)	3	2	3	4	13	2:1919	3	8	0	0.4	1.3	275	[7] 1	1	0	175:1918
Porto Rico	0	0	----------	0	0	8	0	[2] 0	----------	0	0	0	------	------	0	[2] 0	0	0	----------
Rhode Island	0	0	----------	0	0	8	0	[5] 0	----------	0	0	0	------	------	0	(6)	0	0	----------
South Carolina	18	18	8:1920	3	4	1	7	1	5:1922	3	15	0	0.4	2.3	278	[7] 47	0	0	171:1920
South Dakota	20	23	11:1918	3	4	1	6	5	4:1916	4	19	0	0.3	1.5	481	253	2	0	206:1916
Tennessee	21	26	8:1921	4	3	1	54	33	26:1917	11	15	2	2.1	4.9	1,041	969	4	0	395:1917
Texas	67	68	17:1921	6	2	0	152	301	64:1919	20	48	7	2.2	7.6	3,439	27,753	10	0	959:1922
Utah	1	1	1:1916	0	1	7	0	1	----------	0	1	0	------	------	(3)	50	0	0	(3) :1916
Vermont	0	0	----------	0	0	8	0	[5] 0	----------	0	0	0	------	------	0	(3)	0	0	----------
Virginia	6	6	2:1922	1	4	3	1	3	1:1917	1	5	0	0.2	1.0	87	[7] 71	0	0	50:1917
Virgin Islands	0	0	----------	0	0	8	0	[2] 0	----------	0	0	0	------	------	0	(2) (3)	0	0	----------
Washington	1	1	1:1916	0	1	7	0	36	----------	0	1	0	------	------	(3)	[7] 361	0	0	(3) :1916
West Virginia	0	0	----------	0	0	8	0	3	----------	0	0	0	------	------	0	21	0	0	----------
Wisconsin	8	11	3: (4)	3	3	2	18	11	9:1918	4	7	0	1.6	4.5	1,380	3,005	2	0	715:1918
Wyoming	10	10	7:1923	1	3	4	1	1	1:1923	1	9	0	0.1	1.0	25	18	0	0	14:1923
Sum of State numbers	753	810	----------	------	------	------	1929	821	----------	255	555	54	------	------	62,211	77,110	132	15	----------
True number for country	753	754	121:1917	8	0	0	1929	821	508:1917	233	521	48	2.6	8.3	62,211	77,110	124	17	15,205:1920

[1] Partly estimated, because of present lack of details about aggregate losses.
[2] For two years only.
[3] No estimate, but some loss, probably unimportant.
[4] More than one year.
[5] Distribution of the Maryland-Delaware or the New England aggregates between the individual States estimated, at least in part.
[6] No estimate of any loss secured; losses probably considerable.
[7] Reported losses believed to be but a small part of total.

It has already been indicated that the total number of tornadoes is somewhat uncertain. If different compilers should work independently from the original information forward, their counts of the tornadoes would very likely differ considerably; but it is believed that they would vary but little when finding the aggregate loss of life from tornadoes, since the storms of puzzling character are not a large factor in causing deaths.

The total loss of life from 1916 to 1923 was 1,929; these deaths were the work of slightly less than one-third of the tornadoes, 233 out of the 754. More than a third of those tornadoes which crossed State lines caused fatalities in each of two States; and of the 810 tornado occurrences by States it is found 255 involved loss of life.

Among the 41 States in which tornadoes were reported (the District of Columbia counted), 11 escaped fatalities, and in 11 more the death toll per State, over the eight-year period, was less than 10. In other words, but 19 States had an aggregate loss of life from tornadoes of 10 or more, or an average per year of 1.25 or more. These items and many other similar ones are readily determined by inspection of Table 1.

The greatest loss of life in any State occurred in Mississippi, 257; Arkansas came next, with 231; while Alabama was third, with 180. Over one-third of the tornado deaths in the country during this eight-year period happened in one or another of these three States. Only 48 tornadoes, or about one tornado in each 16 occurring, took 10 or more lives, and but one among the 754 caused as many as 100 fatalities, and that one but 103—a tornado of very long path (293 miles), in Illinois and Indiana, May 26, 1917.

Among the years the greatest loss of life is found in 1917, with 508, very closely followed by 1920, with 498. No other year of the eight ran up a total greater than 205.

The smallest toll of a single year in the eight-year period was 109, in 1923.

TABLE 2—*Statistics of tornadoes in the United States by years*

Year	Number	Number of States with—[1]	Aggregate loss of life	Number of fatal tornadoes	Most deaths in a single tornado	Aggregate reported property losses (thousands)	Number of tornadoes causing losses of—	
							$100,000	$1,000,000
1889	21	12	36	10	18	$173	0	0
1890	59	21	194	23	76	4,450	6	1
1891	32	17	16	9	3	187	0	0
1892	44	17	75	17	17	1,118	3	0
1893	83	23	262	40	89	2,044	6	0
1894	57	19	114	26	48	1,193	2	0
1895	32	15	31	9	10	384	0	0
1896	66	25	520	24	306	14,448	6	1
1897	30	16	55	14	14	198	1	0
1916	86	25	140	23	[2] 30	2,511	6	1
1917	121	21	508	54	103	15,008	22	5
1918	81	22	134	30	36	7,631	20	1
1919	65	22	205	15	59	6,861	9	2
1920	87	28	498	29	87	15,205	24	7
1921	106	30	202	27	61	5,406	13	1
1922	108	28	133	37	16	6,630	21	0
1923	100	29	109	18	23	2,959	9	0

[1] Alaska and District of Columbia each count as 1; therefore 50 is the maximum possible score in this column.
[2] Rests on the allotment of 73 deaths caused by a group of 26 or more tornadoes; the exact details of occurrence not now available.

When we turn to the property loss from tornadoes, we again find a considerable uncertainty in the totals. There is not alone the question whether a certain storm is to be classed as a tornado; often no real information can be secured as to appraisal of the damage, though this is more frequently the case with rather unimportant tornadoes; a section director is likely to receive very diverse estimates from different sources; and, finally, the estimates obtained are often admitted to be but for a limited portion of the tornado track. Nevertheless, the aggregate of the estimates, as shown in Tables 1 and 2, is thought to give a fair idea of the total loss and of the distribution by States and by years. Anyone anxious to analyze the results with greatest care may review the detailed material printed in the Reports of the Chief of the Weather Bureau and elsewhere.

During the present study a definite figure has, in a very few cases, been substituted for a somewhat indefinite statement of amount of property loss, such as "several hundred thousand dollars."

The total loss of property reported as due to the tornadoes of these 8 years was in excess of $62,000,000. By years 1920 leads, with $15,205,000, but 1917 shows only a little less, the 2 years together having nearly one-half of the 8-year loss, as, it may be noted, they had more than half of the deaths. The year with least is indicated as 1916, with $2,511,500, but 1923 had only $2,958,750. It is probable that actually the loss of 1923 was the less serious, for the value of property showed a marked increase during the interval, and especially the estimates for 1916 can not be considered so complete as for later years, the system of securing reports being not yet well started, and many helpers finding it not feasible to set a figure in dollars for the damage described.

As with loss of life, the range from year to year in the figures for property losses is much greater in proportion than the range in actual number of tornadoes counted. (See Table 2.)

Among the States, for the 8-year period, Illinois reports considerably the largest aggregate, over $7,500,000; Indiana comes next, with almost exactly $5,000,000, while Minnesota and Iowa are indicated as not far behind Indiana. The largest property loss from a single tornado was in Minnesota, $3,500,000, June 22, 1919, in and near Fergus Falls; next to this was the tornado of very long path, in Illinois and Indiana, May 26, 1917, when the damage amounted to about $3,000,000.

As inspection of the detailed statements about the several tornadoes will indicate, effort has been made to present information, when feasible, covering nine important points for each storm. This paper summarizes but three of those nine points—State of occurrence, loss of life, and loss of property.

The other six items, while less important from a business standpoint, have no little interest. They are: Month of occurrence, hour of the day, length of path, width of path, direction of advance of the tornado, and speed of advance. It is only rarely that a good estimate of the last-named item can be secured or made, and as to some of the others there is frequently little information, at least of such definite character as to make possible tabulation and summation.

It is not feasible at present to summarize the data on these six points. However, it is thought the results, if found, would not differ very greatly from those ascertained by Finley,[3] except that the occurrence by months probably would show relatively fewer during the summer and early fall and more during the spring months.

The period of eight years chosen for this compiling is particularly convenient for comparison with the numbers of tornadoes occurring by States which were found by the late Professor Abbe and presented by him in tabular form.[4]

In the count Abbe rather likely took the numbers for the States which Finley presented in his chart for years down to the end of 1881, and subtracted from those numbers the tornadoes which he counted from the detailed list as occurring before 1874 [5]; these were relatively few, Finley having studied chiefly the years 1874–1881. The numbers for Finley's period, as presented by Abbe, are reprinted without change in the third column of Table 3.

The second column reprints the respective areas of the States, expressed in units of 10,000 square miles, the area of Virginia being corrected from that formerly printed.

The fourth column covers a span of nine years, so as to include the full period that was studied in detail by Henry. The figures which were shown by Abbe for 1889–1896 seem to have been for but seven years and a half, the period covered in the first printing of details by Henry.[6]

Therefore the figures which were printed in the Abbe table have been increased to include the tornadoes of the latter half of 1896 and all the tornadoes, which were comparatively few and unimportant, that are shown for the year 1897. Also a few tornadoes which occurred between the beginning of 1889 and June 30, 1896, are considered to have been unintentionally missed in the counting, and are now counted in; these are mentioned below.

Even with the increases so made, the number of counts for the country during the nine-year period, 1889–1897, is somewhat smaller than the number for 1874–1881, and much smaller than the number for 1916–1923, for which period the figures are brought from Table 1 to the fifth column of Table 3.

[3] Finley, John P. Character of 600 tornadoes. (U. S. Signal Service: Professional Paper 7; Washington, 1882.)
[4] Tornado frequency per unit area. MONTHLY WEATHER REVIEW, June, 1897, 25:250. The table was reprinted, with a correction as to area of South Dakota, in the paper noted in the next line.
Simpson, Howard E. Tornado insurance. MONTHLY WEATHER REVIEW, December, 1905, 33:534–539.
[5] Finley. As above.
[6] Report of the Chief of the Weather Bureau, 1895–1896.

TABLE 3.—*Frequency of tornadoes and tornado deaths, and amounts of property losses*

State or Territory	Area, in units of 10,000 square miles	Aggregate number of tornadoes: 1874–1881, 8 years (Finley)	Aggregate number of tornadoes: 1889–1897, 9 years (Henry)	Aggregate number of tornadoes: 1916–1923, 8 years (Clim. Service)	Aggregate number of tornadoes: Sum, 25 years	Average number of tornadoes per year: Per State	Average number of tornadoes per year: Per unit area	Total loss of life from tornadoes: 1889–1897	Total loss of life from tornadoes: 1916–1923	Total loss of life from tornadoes: Sum, 17 years	Average loss of life: Per tornado occurring	Average loss of life: Per State per year	Average loss of life: Per unit area per year	Aggregate reported property losses from tornadoes (thousands): 1889–1897, 9 years	Aggregate reported property losses from tornadoes (thousands): 1916–1923, 8 years
Alabama	5.1	12	14	35	61	2.4	0.47	2	180	182	3.7	10.7	2.1	$170	$3,797
Alaska	51.7	0	0	0	0	--	--	0	0	0	--	--	--	0	0
Arizona	11.4	2	0	1	3	0.1	0.01	0	0	0	0	0	0	0	(1)
Arkansas	5.2	8	23	76	107	4.3	0.83	20	231	251	2.5	14.8	2.8	582	2,400
California	15.8	1	0	1	2	0.1	0.01	0	0	0	0	0	0	0	17
Colorado	10.4	1	2	7	10	0.4	0.04	0	5	5	0.6	0.3	(3)	1	160
Connecticut	0.5	2	0	0	2	0.1	0.20	0	0	0	--	--	--	0	0
Delaware	0.2	0	0	0	0	--	--	0	0	0	--	--	--	0	0
Florida	5.9	5	1	6	12	0.5	0.08	0	1	1	0.1	0.1	(3)	2	53
Georgia	5.8	29	13	4	46	1.8	0.31	26	63	89	5.2	5.2	0.9	254	1,500
Idaho	8.6	0	0	1	1	(2)	(3)	0	0	0	0	0	0	0	(1)
Illinois	5.5	50	30	24	104	4.2	0.76	201	149	350	6.5	20.6	3.7	3,283	7,536
Indiana	3.4	24	8	20	52	2.1	0.62	0	131	131	4.7	7.7	2.3	44	5,016
Iowa	5.5	26	32	66	124	5.0	0.91	178	40	218	2.2	12.8	2.3	608	4,446
Kansas	8.1	55	53	69	177	7.1	0.88	103	61	164	1.3	9.6	1.2	967	3,622
Kentucky	3.8	5	12	8	25	1.0	0.26	123	75	198	9.9	11.6	3.1	2,933	2,080
Louisiana	4.1	11	10	13	34	1.4	0.34	22	42	64	2.8	3.8	0.9	172	1,260
Maine	3.5	3	3	0	6	0.2	0.06	3	0	3	1.0	0.2	0.1	13	0
Maryland	1.1	8	3	1	12	0.5	0.45	3	0	3	0.8	0.2	0.2	31	100
Massachusetts	0.8	7	1	2	10	0.4	0.50	8	0	8	2.7	0.5	0.6	60	400
Michigan	5.6	13	8	24	45	1.8	0.32	50	16	66	2.1	3.9	0.7	649	3,082
Minnesota	8.4	21	26	12	59	2.4	0.29	35	99	134	3.5	7.9	0.9	595	4,767
Mississippi	4.7	9	20	42	71	2.8	0.60	45	257	302	4.9	17.8	3.8	316	3,698
Missouri	6.5	40	17	57	114	4.6	0.71	174	123	297	4.0	17.5	2.7	10,734	3,507
Montana	14.4	1	0	9	10	0.4	0.03	0	2	2	0.2	0.1	(3)	0	4
Nebraska	7.6	14	22	36	72	2.9	0.38	12	7	19	0.3	1.1	0.1	688	902
Nevada	11.2	1	0	0	1	(2)	(2)	0	0	0	--	--	--	0	0
New Hampshire	0.9	3	0	1	4	0.2	0.22	0	0	0	0	0	0	0	10
New Jersey	0.8	5	7	2	14	0.6	0.75	4	0	4	0.4	0.2	0.2	81	(1)
New Mexico	12.1	1	0	8	9	0.4	0.03	0	0	0	0	0	0	0	19
New York	4.7	20	7	6	33	1.3	0.28	5	2	7	0.5	0.4	0.1	76	335
North Carolina	5.1	14	3	11	28	1.1	0.22	3	8	11	0.8	0.6	0.1	22	547
North Dakota	7.1	4	2	19	25	1.0	0.14	0	10	10	0.5	0.6	0.1	(5)	128
Ohio	4.0	21	9	23	53	2.1	0.52	8	40	48	1.5	2.8	0.7	207	3,187
Oklahoma	6.9	1	18	50	69	2.8	0.40	59	144	203	3.0	11.9	1.7	175	2,632
Oregon	9.5	0	1	0	1	(2)	(3)	[4] 5	0	[4] 5	[5] 5.0	0.3	(2)	(1)	0
Pennsylvania	4.6	17	14	11	42	1.7	0.37	44	4	48	1.9	2.8	0.6	634	275
Rhode Island	0.1	0	0	0	0	--	--	0	0	0	--	--	--	0	0
South Carolina	3.4	13	4	18	35	1.4	0.41	1	7	8	0.4	0.5	0.1	15	278
South Dakota	7.6	5	22	23	50	2.0	0.26	13	6	19	0.4	1.1	0.1	94	481
Tennessee	4.6	15	10	26	51	2.0	0.43	4	54	58	1.6	3.4	0.7	90	1,041
Texas	27.4	18	40	68	126	5.0	0.18	144	152	296	2.7	17.4	0.6	682	3,439
Utah	8.4	0	0	1	1	(2)	(3)	0	0	0	0	0	0	0	(1)
Vermont	1.0	2	0	0	2	0.1	0.10	0	0	0	--	--	--	0	0
Virginia	4.0	9	3	6	18	0.7	0.17	2	1	3	0.3	0.2	(2)	3	87
Washington	7.0	0	0	1	1	(2)	0.01	0	0	0	0	0	0	0	(1)
West Virginia	2.3	1	1	0	2	0.1	0.04	2	0	2	2.0	0.1	(2)	3	0
Wisconsin	5.3	11	10	11	32	1.3	0.25	4	18	22	1.0	1.3	0.2	8	1,880
Wyoming	9.8	1	0	10	11	0.4	0.04	0	1	1	0.1	0.1	(3)	0	25

1 No estimate, but some loss, probably unimportant.
2 Less than 0.05.
3 Less than 0.005.
4 Aggregate only $300.
5 Evaluation of "several."

The 1896–1897 report, containing the only list for the last half of 1896, reprints the items for the first six months, adding accounts of several tornadoes during that period which came to notice too late for including in the earlier printing. With respect to one tornado in Kansas, designated 11a in the earlier printing, the omission from the list as reprinted is thought unintentional, so the tornado is now counted.

Three omissions before 1896 were noted and have been corrected in carrying the numbers to Table 3. The 0's of West Virginia and Oregon were each changed to 1, for the lists indicate a tornado in each State, the dates being, respectively, May 30, 1889 (No. 9), and June 3, 1894 (No. 19). Mention in the MONTHLY WEATHER REVIEW [7] was noticed of a tornado at Baird, Tex., July 25, 1895, which caused one death, yet is unlisted in the tornadoes of the year.

Owing to the political developments since 1897, data for Indian Territory, where presented separate from the like items for Oklahoma, are now included in the Oklahoma figures. The counts for Oklahoma and Texas seem to show very marked increases in number of tornadoes occurring, but these gains are thought to be chiefly a matter of more complete reporting, following on settlement and development of large portions of those States which were but very little used till within a comparatively few years.

To the eastward of Oklahoma and Texas, however, the count of tornadoes for 1916–1923 is found to show a very marked gain in number, far greater than the average gain of the whole country. In Alabama and Mississippi, where over twice as many were noted per year as were reported a generation ago, it seemed wise to examine the details with special care. As no extensive new settlements have been made recently in these States, it seemed likely that attention might now be paid to tornadoes causing no deaths or few, as compared with failure in the earlier periods to report such storms. But inspection shows that the Henry period included in these States an even larger proportion of no-death and few-death storms than the recent period. So the large increase in number reported seems to mean a genuine increase in occurrences—the recent years chanced to have many.

Yet considering the whole country, the moderate increase in number since the 18-year interval is thought to be considerably, but by no means wholly, due to

7 MONTHLY WEATHER REVIEW, July, 1895, 23:244.

change in method of counting when individual tracks are not far distant, not in line, and yet are distinct from one another, or substantially so, from start to finish. The tornado occurrences in northern Texas, May 15, 1896, were counted but 1, while the present method would be to count 5, for 5 distinct clouds and paths were noted. Had the simultaneous tornadoes of May 4, 1922, at Austin, Tex., 3 miles apart, been handled in the 1890's, the count probably would have been but 1, and not the recent count of 2. In the very nature of things, counting of tornadoes can never be on as satisfactory a basis as the counting of sheep or of farmhouses.

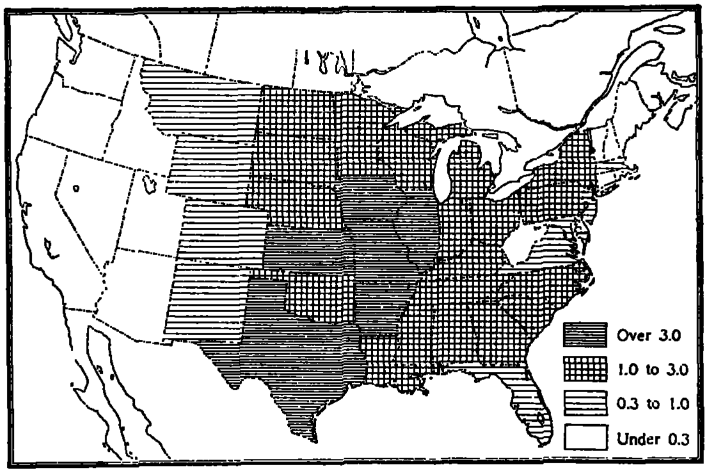

FIG. 1.—Average occurrence of tornadoes, per year per State, for 25 years

The sum of tornadoes for the three detached periods, 25 years altogether, is placed in the sixth column of Table 3. The seventh and eighth columns indicate the average number per year in each State as a whole and the average per year per unit area in each State. These three columns follow the plan of the three right-hand columns of the Abbe table. Figure 1 indicates graphically the average annual number per State.

The sums of the State numbers for the Finley, the Henry, and the recent periods, are 509, 449, and 810, respectively, or 1,768 for the 25 years. The true numbers for the whole country, from scanning of Finley's and Henry's lists and from Table 1, seem to be 506, 424, and 754, therefore 1,684 in all, which means an average of 67 tornadoes counted each year.

The two smallest States, Rhode Island and Delaware, are indicated as without tornadoes during the 25 years. In the former, however, Finley reports a tornado as having occurred during August, 1838.[8]

While tornadoes are evidently infrequent in the far West, yet no State there seems to be quite without them. In Oregon and Washington tornadoes and severe local winds seem not to have been reported yet from any point west of the Cascade Range.[9] Examining the whole area west of the Continental Divide, we find but two tornadoes involving loss of life, in Oregon and Montana, respectively.

In 1922 Colorado reported a few deaths by tornadoes, and in 1924 others occurred. This State extends farther eastward than either Wyoming, which is north of it, or New Mexico, south of it. If a line be drawn across Colorado from the southeastern corner of Wyoming to the northeastern corner of New Mexico, it will appear that all these deaths just referred to happened to eastward of the line.

The ninth to fourteenth columns of Table 3 are given to statistics of losses of life, those for the recent period being brought from Table 1 and those for 1889–1897 being compiled from the printed lists, with a very few allotments necessary when a tornado crossed a State border and the death toll for only the entire path is now available. For the Finley period even approximate statistics are not to be had. Totals for 17 years are computed, and division by the numbers of tornadoes occurring during those years (not printed) furnishes the average losses of life per tornado occurring. Average losses per year and per unit area per year are presented in the next two columns.

The tornado deaths for the country total 1,303 for the Henry period, and 3,232 for the 17 years. Per tornado occurring, 3,232 divided by 1,178, the average is 2.7; but per fatal tornado the average is 8 (3,232 divided by 405). The average number of deaths per year per State is indicated by Figure 2.

The two right-hand columns of Table 3 are used for data as to property losses. Again the Finley period does not yield information that can be put into statistical form, so only the years covered by the columns for losses of life are included.

The statistics by States for losses by tornadoes during 1889–1897 almost exactly follow those presented by Henry,[10] but some revisions have been made. The immense loss of the St. Louis tornado, May 27, 1896, instead of being placed wholly in the Missouri column, is now divided between that State and Illinois, according to the details printed at the time.[11]

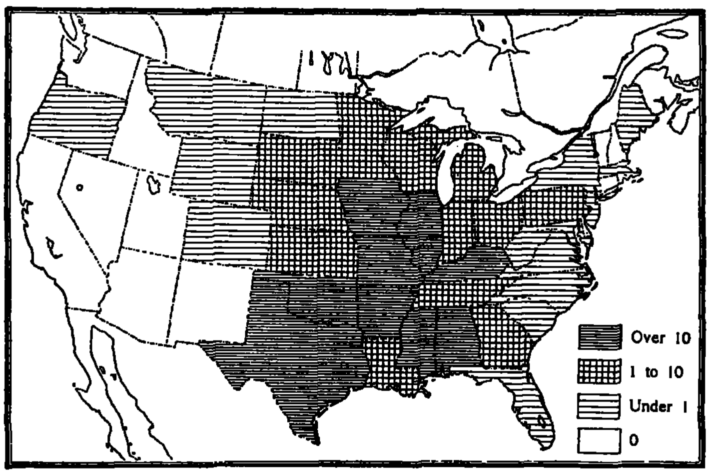

FIG. 2.—Average loss of life from tornadoes, per year per State, for 17 years

The other losses of 1896 have been computed over again from the list for the entire year, the loss of the dropped Kansas tornado, No. 11a in the first printing, being included.

The change in the value of the dollar, since the period studied by Henry, has been so great that it is considered unjust to add the 1889–1897 losses, State by State, to the 1916–1923 losses, and then compute averages. In States like Missouri and Pennsylvania, for which the greater number of dollars is stated for the earlier period, the computed averages would not be properly comparable with the averages for such States as Indiana, North

[8] Finley, as above, p. 4.

[9] This statement does not apply to winds covering belts many miles broad and sustained for a longer period than the thunder squall. Such winds, however, are included in the two columns of Table 1 stating deaths and losses from winds not tornadoes.

[10] Report of the Chief of the Weather Bureau, 1897–1898, p. 304.

[11] MONTHLY WEATHER REVIEW, March, 1896, 24 : 80

Dakota, and Wisconsin, where the damage of the early period was quite insignificant compared with that of the later period.

The canvass of the country by the Climatological Service is continuing. The synopsis for 1924 has not yet (May, 1925) been prepared, but enough is already known to make sure that the year will include a greater property loss from tornadoes than that of any one year covered by Table 2, that is, the figure in dollars will be a larger one; it will probably be the highest figure for a year in the country's history. Furthermore, 1925 has already witnessed (March 18) the most serious single tornado ever known, and so the 1925 death toll is expected to exceed that of any previous year, save perhaps 1884, and its figure for damage will very likely surpass that of 1924.

In handling the reports of tornadoes the writer has at times noticed how narrowly a violent storm escaped being entirely unreported. It is thought that a few tornadoes, though probably not many, still occur in sparsely settled parts of the country without any news of them reaching the Weather Bureau.

In closing, the writer wishes gratefully to acknowledge the advice and assistance given by many Weather Bureau colleagues, particularly by Prof. A. J. Henry and Mr. P. C. Day; also by Dr. Charles F. Brooks.

THE 11-YEAR PERIOD OF TEMPERATURE IN THE NORTHERN HEMISPHERE IN RELATION TO THE 11-YEAR SUN-SPOT CYCLE

By Dr. FRANZ BAUR

[Wetter- und Sonnenwarte, St. Blasien, Germany, October, 1923]

The analytical method for investigating the periods in the course of the weather is essentially superior to the graphical method which has hitherto been almost exclusively adopted. Its application to the annual mean temperature for the period 1876–1919 of a number of European and North American meteorological stations shows that the maximum of the 11-year temperature period on the whole earth in no way coincides with regard to time even approximately with the minimum of solar activity as has been assumed up to now. In large areas of the Temperate Zone of the Northern Hemisphere the maximum of the 11-year temperature period occurs between the minimum and maximum of the sun-spot cycle; in some continental European regions it even coincides with the maximum itself. The shifting of the phases of the two periods seems to be determined by the latitude and climatic position of the place of observation. It is very probably a physical reality and due to the difference between the diathermancy of polar and tropical atmospheres. The greatest amplitudes are shown by the 11-year temeperature period in those regions in which its maximum falls about on the minimum of the sun-spot cycle. In the other regions, it has but little importance with regard to the annual mean temperature and falls far into the background compared with other periods.

The widespread opinion that the maximum of the 11-year temperature period coincides approximately on the whole earth with the minimum of the 11-year sun-spot cycle is based in the first place on the work of Köppen [1] and Mielke,[2] who, in deducing their results, adopted the graphical method of representing the course of temperature. A work on the sun-spot terrestrial temperature relations in the United States [3] which has recently appeared is also based on this method. The graphical method is, however, little suited to the investigation of periodic phenomena, for with it are necessarily connected smoothing processes in order to eliminate from the graph lesser periods than the required one, or the one under investigation. These smoothing processes tend both to obscure some really existing period and to make apparent a nonexistent one. But more important is the fact that these smoothings of the graph change in most cases the phase of the required period considerably. Therefore, the relation between the phases of the 11-year temperature period and those of the sun-spot cycle as set forth by Köppen and Mielke, can not be accepted, being insufficiently proved. Such a relation can only be established by a strictly mathematical method.

One of the best mathematical methods of investigating periodicities is the representation of the given function by a Fourier series. There is, in general, no real difficulty in resolving any empiric numerical function into a Fourier progression since the convergence of the progressions, which are of the general form

$$f(t) = \tfrac{1}{2}a_0 + a_1 \sin t + a_2 \sin 2t + \text{------} \\ + b_1 \cos t + b_2 \cos 2t + \text{------}$$

is determined in large measure by mathematical theory. In meteorology, however, the problem becomes difficult, since it is a matter of compound functions of the form

$$f(t) = \tfrac{1}{2}r_0 + r_1 \sin (T_1 t + \phi_1) + r_2 \sin (T_2 t + \phi_2) + \text{------}$$

whose terms are not of definite number but, in general, of any number of incommensurable periods. Even if, as in the given example, it is only a matter of calculating a single period, the amplitude and phase resulting from Fourier's analysis for this one period may yet be falsified by the coexistence of other incommensurable periods. For each ordinate of the unsmoothed course of a phenomenon subject to periodic oscillations is the sum of several ordinates belonging to different periods. In order to eliminate the influence of other periods in determining the amplitude and phase of a period by means of Fourier's analysis, it is necessary either to examine a very large series of observations such as hardly yet exists in most cases for meterological purposes, or else a period of time must be made the basis of the calculation which is, at least approximately, a multiple of each of the existing periods.

Since in previous works [4] I have come to the conclusion that very probably there are contained in the fluctuations of temperature both a 2.4 and a 7.2 year period, I chose, for the determination of the phase shiftings of the 11-year temperature period, a period of 44 years, for this is approximately a multiple of 2.4, 7.2, and 11 years. The choice of a still longer period of time would not have been feasible, for the reason that the period is not exactly 11 years, but 11.1–11.4, so that in dividing the whole period of observation into intervals of 11 years

[1] Köppen W., Ueber mehrjährige Perioden der Witterung, insbesondere über die 11-jährige Periode der Temperatur. Zeitschr. der Oesterr. Gesellschaft für Meteorol. VIII, 1873, XV, 1880, XVI, 1881; Meteorol. Zeitschr. VIII, 1891, XXXI, 1914.

[2] Mielke Johannes, Die Temperaturschwankungen 1870–1910 in ihrem Verhältnis zu der 11-jährigen Sonnenfleckenperiode. Archiv der Deutschen Seewarte, XXXVI, No. 3, 1913.

[3] Henry A. J., Sun spots and Terrestrial Temperature in the United States. Mo. Weather Review, May 1923, vol. 51, pp. 243–249.

[4] e. g., F. Baur, Die Veränderlichkeit der Temperatur aufeinanderfolgender Monate und die periodischen Schwankungen der Jahrestemperatur in Deutschland, Abstract in Mo. Weather Review, April, 1922.